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PREDICTING WIRELESS LINK DEGRADATION FROM OBSERVATION AGAINST A KNOWN TOPOLOGY

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ABSTRACT

Presented herein are techniques to utilize wireless microwave network links as sensors to feed into a customized weather model for use in targeted weather forecasts that can include information regarding observed effects of weather on the wireless transmission links. Such techniques may allow quick adaptation when storms are developing faster than micro-forecasts can be updated by centralized prediction services and may improve the relevance and/or direct interpretability of forecasts to network performance. In various implementations, the weather can be computed centrally within a single router.

DETAILED DESCRIPTION

Microwave devices are a common component in mobile backhaul networks, often being significantly cheaper than laying optical fiber either in dense metro areas or due to geographical constraints in rural locations. However, a downside of microwave transmissions is that microwave signals are affected by atmospheric conditions and can degrade, for example, during heavy rain.

A goal of the techniques described herein is to minimize or reduce packet loss and latency across wireless communications links resulting from medium-duration transient degradation of a link's capacity resulting from meteorological phenomena. This is not a new problem.

Historically, meteorological phenomena have led to a complete loss of communication signals but more modern microwave devices support adaptive modulation schemes. This allows such devices to continue to operate during periods of degradation but at a reduced bandwidth. However, to fully take advantage of adaptive modulation schemes, it is necessary to signal the decrease in bandwidth to the head-end router so that appropriate action can be taken.

Otherwise the link may become saturated and traffic may be dropped. Thus, it would be desirable to develop a common mechanism by which radio transceivers can communicate to the routers/switches the available bandwidth over the microwave link. This mechanism may be based on extensions to the International Telecommunication Union (ITU) Telecommunication Standardization Sector (ITU-T) Y.1731 protocol.

Path loss (or path attenuation) is the reduction in power density (attenuation) of an electromagnetic wave as it propagates through space. Path loss is a major component in the analysis and design of the link budget of a telecommunication system.

A disadvantage of microwave transmission is that microwave towers can exchange data only if they have a clear line of sight between them with no obstacles in the way, such as buildings, slopes, or trees. Different disadvantages incorporate signal absorption by the atmosphere, weather obstructions, and cost. Electromagnetic interference, or EMI, can obstruct or degrade the performance of microwave signals. Microwave radio communication can also be degraded by heavy moisture in the atmosphere, such as snow, rain, and/or fog, through a phenomenon known as rain fade. Without optimizing network performance during an inclement weather event can result in a large loss in a microwave network.

Thus, it may be desirable to dynamically alter network performance based on the weather forecasts and the application requirements. While weather forecasts may sometimes not be accurate, they often do provide relatively good information on what is likely to occur over a period of a few days. As a result, weather forecasts may provide ample lead-time to alter network parameters or behaviors and increase overall network performance.

In addition, presented herein is a novel strategy for addressing weather-related network degradations by using the wireless network itself as a sensor network to track the intensity and duration of network degradation, and use these observations to predict the effects on other links in the network. A key feature of this proposal is to combine geographic data with observational data reflecting the actual (observed) effects on transmissivity in order to predict atmospheric conditions for multiple links in a network.

Thus, techniques presented herein involve combining predicted effects with observed effects in order to improve the relevance of micro-forecasts to a network.

Although some currently available micro-forecasts are relatively accurate (e.g., providing estimates of rain intensity on quarter-hour cadence for 4 square kilometer regions), such currently available micro-forecasts may contain noise at the scale of point-to-point communications. Further, reliance on an externally supplied forecast may not reflect actual environmental conditions, either due to natural error in the forecasts or failure to deliver to the router in a timely fashion.

The solution proposed herein is to treat microwave communication links between devices as probes of the atmosphere (e.g., with a keep alive/ping running across the links at some nominal rate–low enough to not be disruptive, but high enough to estimate packet loss).

Imagine a geography overlaid with a hexagonal grid in which hexagons between two towers can be "colored" to indicate with the current transmissivity. Information from the current weather state, the current probed link state, and the projected weather state could be combined to predict the effects on transmissivity on the links in the network. This may enable tracking the degradation over time through the network, with a projected path of network nodes having their configuration proactively adjusted in anticipation of the degradation, and then returned to a normal operating state when the degradation has passed in which the adjustments are guided by out-of-band data.

The prediction could be done from any outside source, or could be generated from the observations themselves. Consider an example scenario involving three links A, B and C arranged in a linear fashion such that link A is 'a' kilometers (km) from link B and link B is 'b' km from link C. Further for this example scenario, consider that a storm is moving into link A and the routers at either end of link A might be able to communicate between each other an indication that transmissivity along link A is at first lightly disrupted and then heavily disrupted. Additionally, if the routers at either end of link B might also communicate an indication that transmissivity along link B is at first lightly disrupted and then heavily disrupted and if link B's routers know the reports from the link A routers, a velocity vector for the two disruption event types can be determined and can be propagated, looking for an intersection between the direction of travel and other links for the network. In particular, the routers at either end of link C could compute the time remaining until a light disruption and a heavy disruption would be expected (and then "light disruption" and then "clear" again). The routers at either end of link C may utilize such information to attempt to mitigate any disruptions for link C.

Thus, techniques herein provide for the ability to utilize both micro-forecasts and micro-observations, with the benefit that the micro-observations can be built into the network elements at which improvements may be realized and at which the reality of certain events can be confirmed before allowing a configuration to be adjusted back to a "normal" state.

Consider another operational example, via a set of map illustrates, as shown below in Figures 1–8. For example, as shown in Figure 1, consider that five radio networks are interconnected. At 10:00 AM, consider that each of the links is operating at 100% capacity, with no network degradations identified. Consider further, as shown in Figure 1, that a centralized entity obtains inputs from a weather report satellite and also obtains network strength and telemetry data from various network nodes.

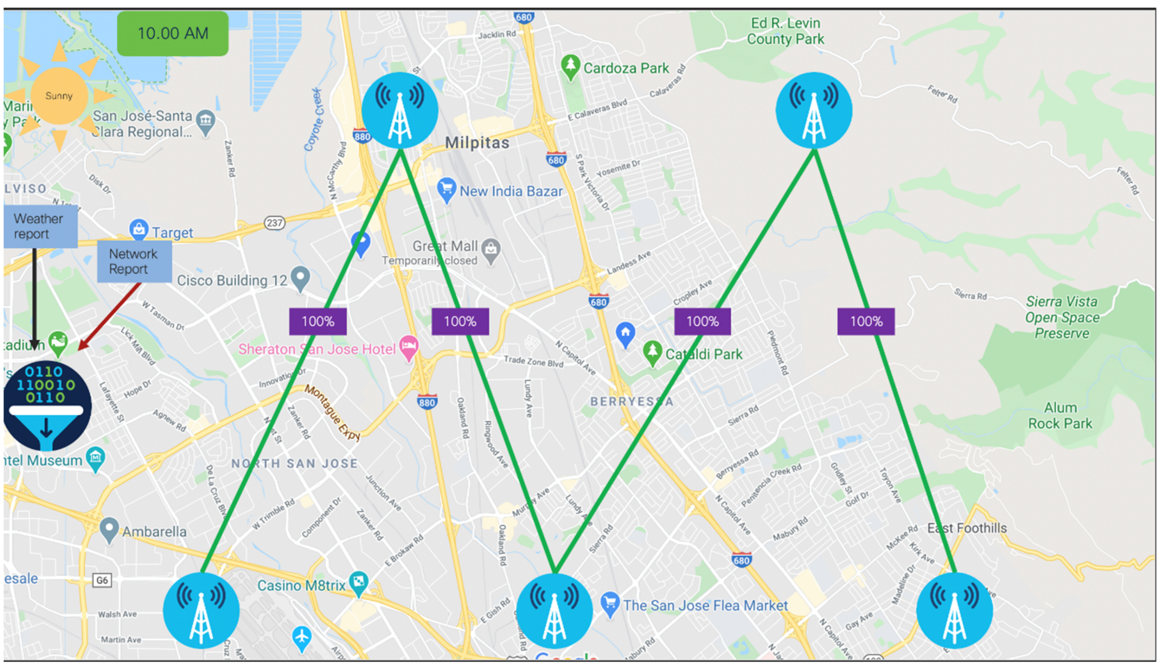

Figure 1: Example Network Topology

Next, at 10:05 AM as shown in Figure 2, below, the central entity determines a rain prediction via a weather satellite/radar and continues collecting data in order to determine a direction of the thunderstorm.

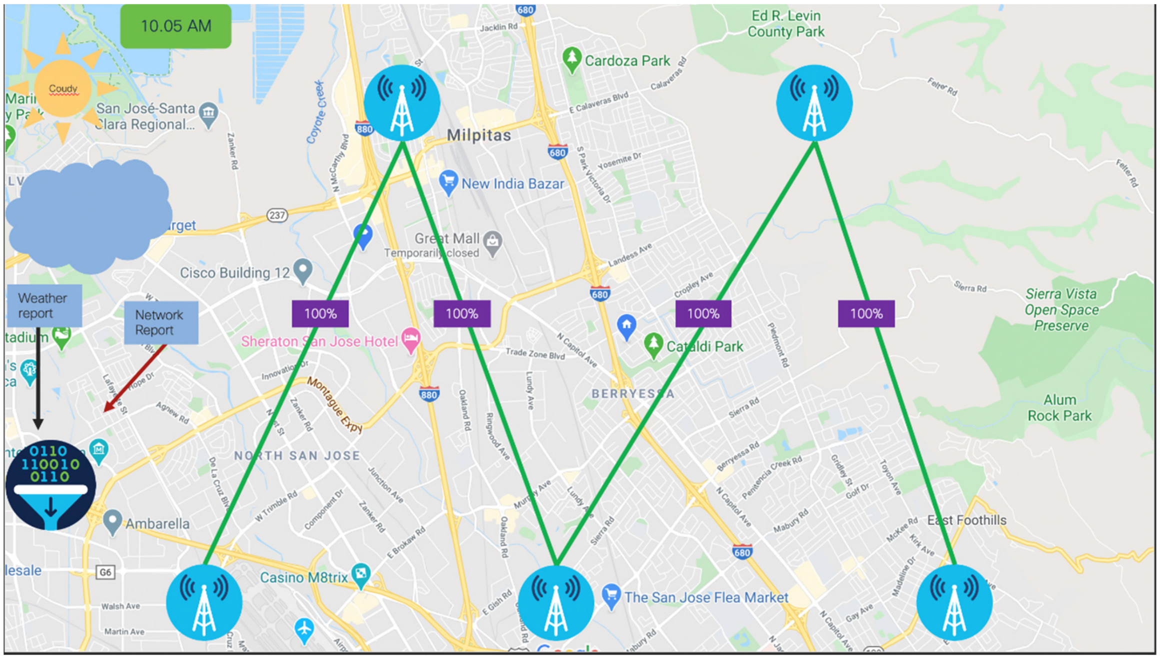

Figure 2: Storm Determination

Next, at 10:10 AM as shown in Figure 3, it is determined that the thunderstorm has reached a point that it is between two radio towers such that the quality is degraded by 5% in a left-most link.

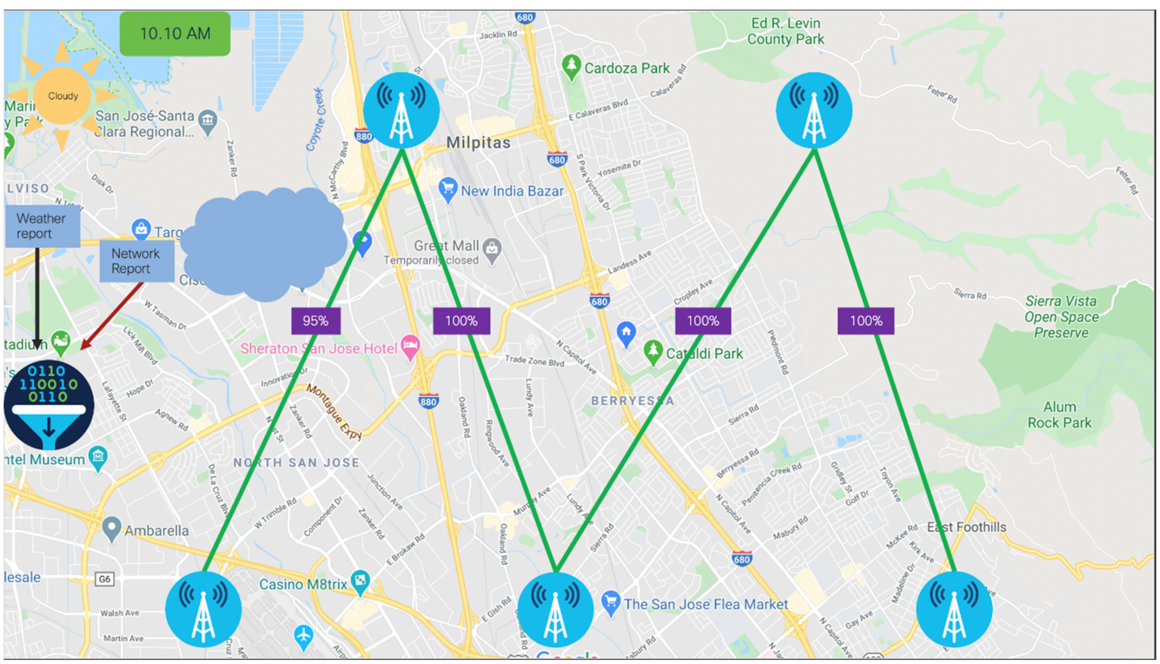

Figure 3: Storm Between Two Towers Causing Degradation

Then, at 10:15 AM as shown in Figure 4, the thunderstorm continues moving eastward and the quality degrades further. The centralized entity continues to obtain data from the network to determine the degradation.

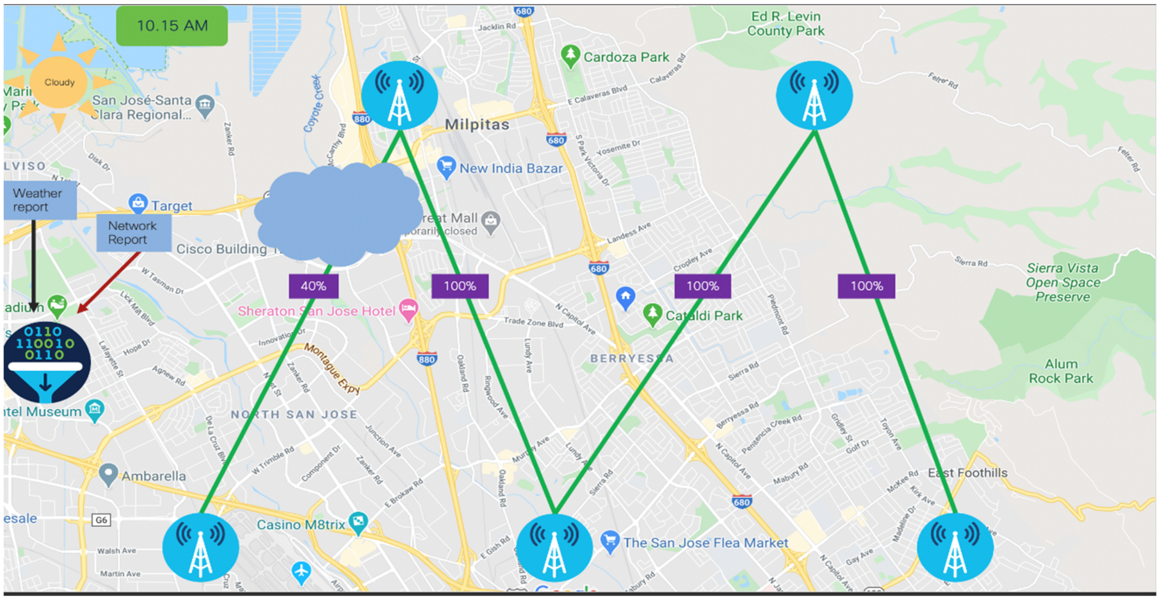

Figure 4: Storm Continues Eastward and Degradation Increases

Then, at 10:20 AM as shown in Figure 5, the centralized entity determines, based on the data obtained, a prediction that the thunderstorm is going to move further east and predicts a new degradation metric for the links.

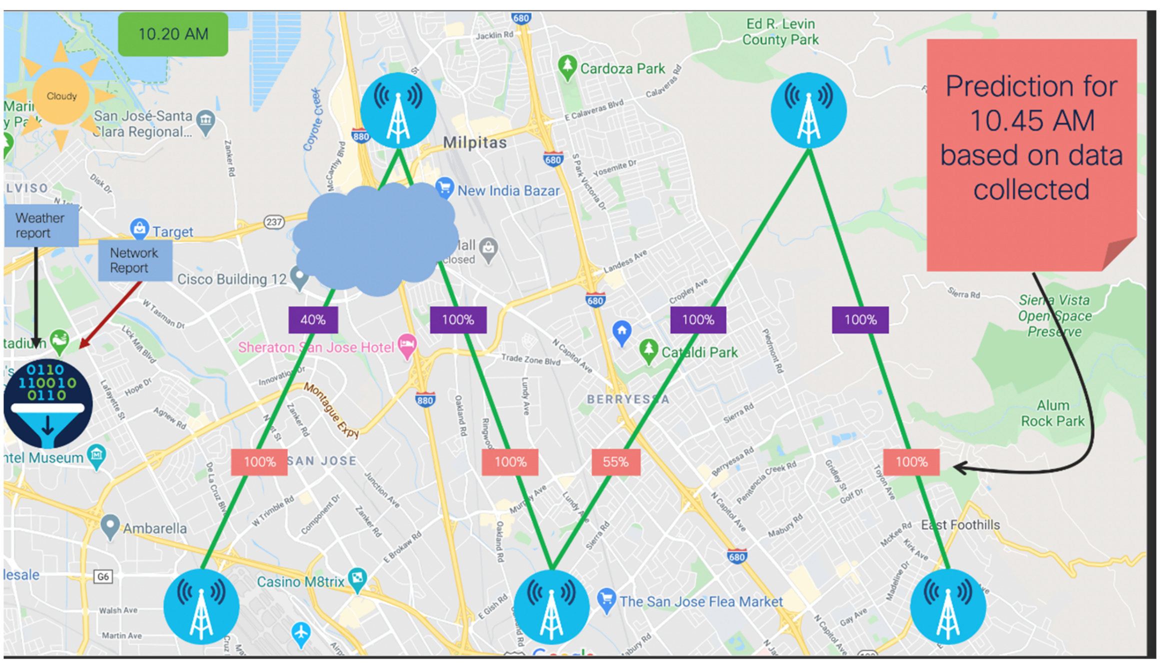

Figure 5: Predicted Network Degradation

Based on the predicted degradation, the network can readjust the usage of links to accommodate weather changes.

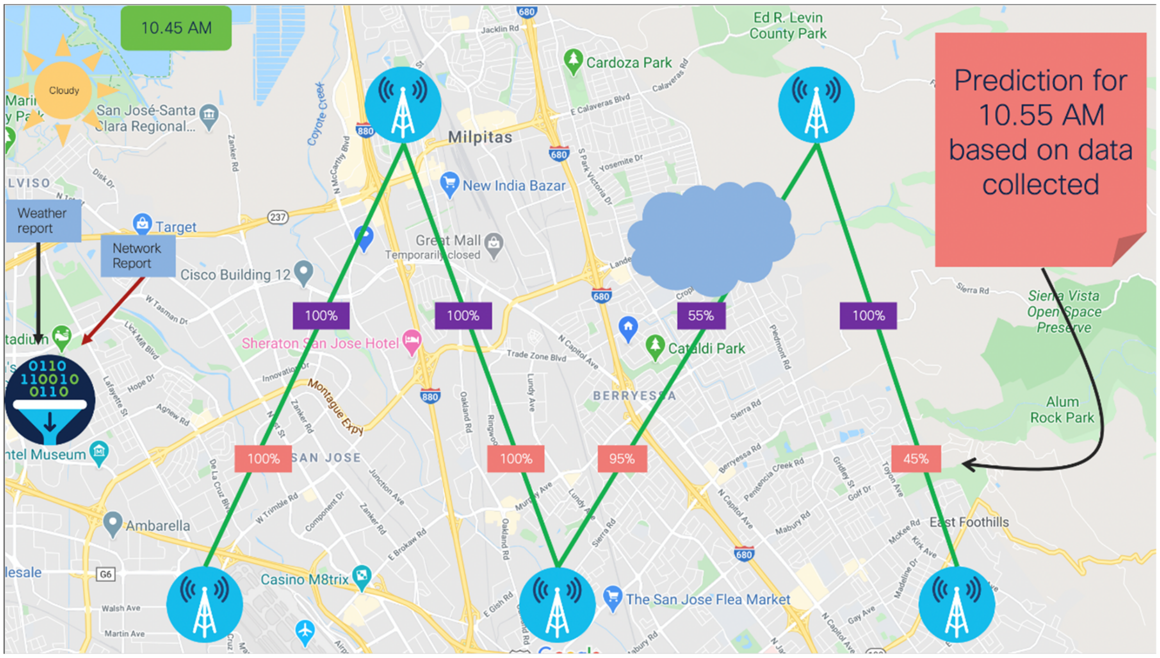

Figure 6: Additional Network Degradation Prediction

As shown in Figure 6, above, since the network has accommodated usage based on the prediction, the network does not have any drops and, based on the direction of movement for the thunderstorm, additional predictions can be performed for the network

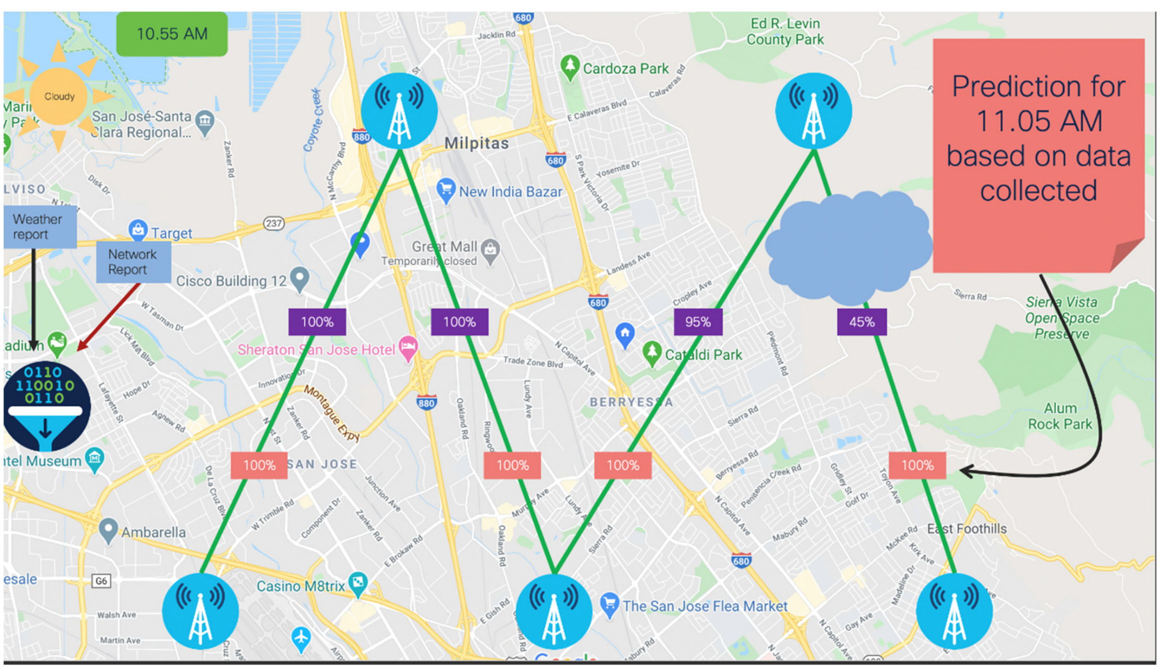

Figure 7: Prediction of Full Use for Network Based on Storm Movement

For example, as the thunderstorm moves further east, network availability parameters are changed and the network is adjusted based on the new parameters. For instance, in this example a prediction based on current data may indicate that the network is going to be available for full use in the next 10 minutes, as shown in Figure 7, above.

Finally, as shown in Figure 8, it is detected that weather is now normal, and the network can be used at its full capacity. Additional predictions can further be performed for the network, as shown in Figure 8.

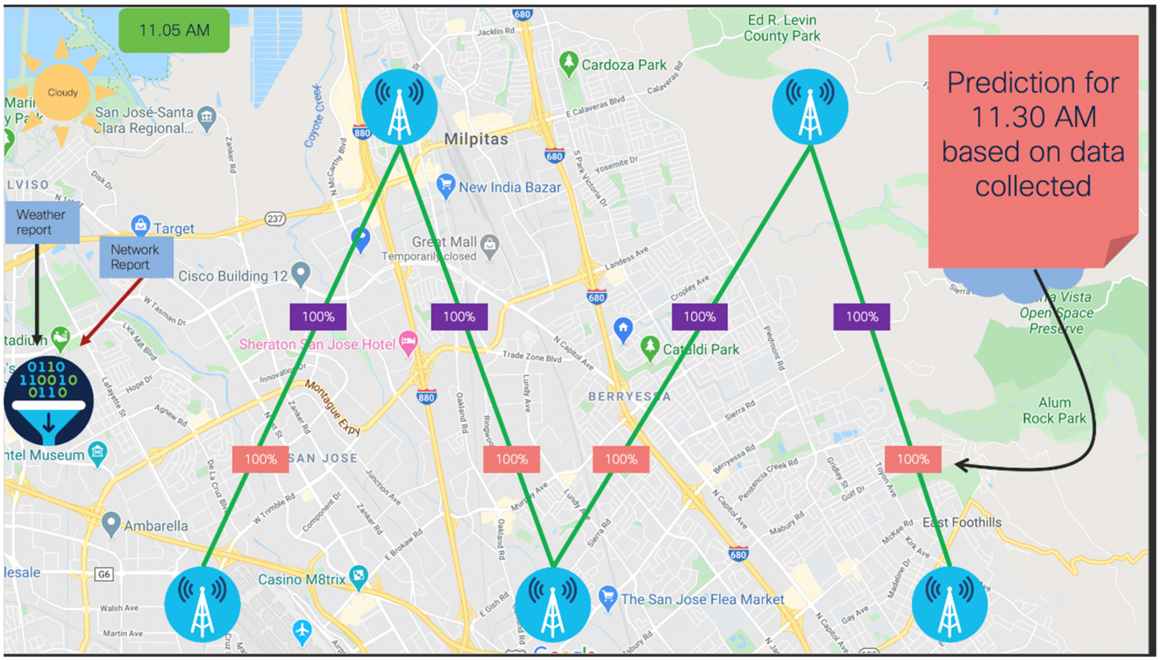

Figure 8: Network Can Be Used At Full Capacity

In summary, techniques of this proposal include two primary features, 1) prediction of future network outages and/or degradation and 2) providing proactive network decisions rather than reactive network decisions. These features may be implemented via an external entity that can utilize micro-forecast information to proactively change/update optimal network configurations reflecting anticipated degradation of one or more links. In addition, the external entity can also facilitate confirmation/determination of link state/capacity via one or both ends of a link in order to determine when capacity has returned to normal or transitioned to a next anticipated link state. As weather patterns are unpredictable, the external entity can obtain weather-related information via known observations, which may be more lethal/useful as compared to attempting to predict weather, utilizing techniques such as machine learning, etc. In various implementations, predictions could be provided by any outside source and/or could be generated from observations themselves.

Advantageously, techniques herein are not focused on predicting weather, rather predictions are associated with observations of an external entity's prediction of weather and the current capacity of the links in which such information is combined in order to determine or predict a direction of impact of weather events on a microwave network.

For example, based on data obtained by the centralized/external entity, the entity can determine a prediction that a thunderstorm is going to move in a particular direction. Based on this data, devices can readjust link usage to accommodate weather changes. The model can be run from the external entity or within the devices themselves. Network strength and telemetry data from nodes can be used to obtain an accurate picture of the state of network devices at a particular time for a weather event. Predictions based on observations will feed that data to the devices that can adjust link bandwidth based on the received data received, which can help to eliminate packet drops to manage link capacity based on expected degradation.

Further, it will be useful to track degradation over time through a microwave network, with a projected path of affected network nodes having their configuration proactively managed in anticipation of an expected degradation, then returned to a normal state when the degradation has passed in which such changes are guided by out-of-band data.

Techniques herein may be feasible not only because there are numerous micro-forecast services, but also because microwave towers themselves can be in techniques of this proposal. For example, consider a simple network topology with an emphasis on rain and/or a thunderstorm moving through a small geography in which a degradation passes through the area and a schedule of planned changes to the admission control parameters and/or the routing/forwarding tables in each device over time can be generated as a set of network states. Consider the following example network states that can be determined for the present example, as follows:

- Network state 0: graph of link capacities with an "optimal" and "normal" configuration covering a geographical region, represented as [A , B];

- Network state 1: graph of link capacities with an implied impact of a weather event for region A;
- Network state 2: graph of link capacities with an implied impact of the weather event for regions A and B;
- Network state 3: graph of link capacities with an implied impact of the weather event for region B; and
- Network state 4: graph of link capacities with "optimal" and "normal" configuration covering the geographical region [A, B].

Thus, as illustrated through the above example, techniques herein may not be focused on capacity planning, but rather may be focused on the combination of out-of-band or in-device/sensor data with information about forthcoming degradations to facilitate proactive reactions in a network. In one instance, data collected by a sensor may be represented as, sensor_i(t) = OBSERVED union PREDICTED = { v_t | t <= NOW } UNION { v_t = f(w) | w_i = sensor_j(), t > NOW, 0 <= j <= N }. Both observed and predicted data can be utilized in a manner such that the predicted data is the predicted value of a sensor as a function of the N + 1 links observed, whether those N + 1 links are from a particular tower and/or a connected network towers. Accordingly, techniques herein may facilitate the use of the network itself as a sensor network to feed a custom forecasting engine for the network to proactive reactions to update/manage wireless links in the network.

Non-proactive reactions may have several drawbacks. Different network uses are becoming more crucial and end user quality of service/experience is important. Reactions to failures that are performed after detecting a quality degradation may be untimely, as such degradations may move quickly through a network.

In contrast, proactive reactions may provide several benefits, including potentially providing more opportunities for maintaining non-interrupted services to an end customer, even when during inclement weather. Additionally, proactive reactions may make better use of different sensor data that can be collected through different mechanisms. Further for proactive reactions, data may be utilized such that a system can automatically react and recover from uncontrolled failures. Still further, proactive reactions may facilitate high availability and reliability to end users.

Although it is understood that a given cell tower in the middle of an active thunderstorm or heavy rain event may have all links affected, it is quite common for precipitation events to be fairly local and short duration, with the average thunderstorm being 15 miles in diameter with a roughly 30 minute lifespan. 'Single cell' thunderstorms are often smaller, perhaps only a few miles in diameter, such that a thunderstorm (or even a heavy pop-up rain event) may pass between nodes of a network and may be observed 'from the side'. However, this proposal illustrates that it can be advantageous to incorporate ground truth information into network reconfiguration procedures. Further, combining information from ground truth observations and predictions can be utilized to take appropriate reconfiguration actions in order to minimize negative impacts on a network.

Accordingly, techniques herein provide for the ability to utilize observed link characteristics directly as one of the inputs to a predictive model that may represent network performance impacts in which the deployment topology of the managed network can be used to focus the modeling effort. This can be performed on the link degradation data itself, without any external weather information and with a relatively simple Bayesian approach modelling the question 'what is the predicted link state for all network links given the observed link state for all network links over the last 60 minutes?' The availability of micro-forecast and select observational (meteorological) data can increase the data available to the model and might improve the result, but such data is not imperative to perform techniques presented herein.